How Do Martian Dust Devils Vary Throughout the Sol?

Conference or Workshop Item

Paper # P21B-2085

Rhian Chapman
Postgraduate Research Student
rhian.chapman@open.ac.uk

Presenting poster:
Tuesday, 09:00-11:00

How Do Martian Dust Devils Vary Throughout the Sol?

Rhian Chapman[1], Stephen Lewis[1], Matt Balme[1], Liam Steele[1]

[1]The Open University, School of Physical Sciences, Walton Hall, Milton Keynes, MK7 6AA, UK

AGU Fall Meeting 2016
12th-17th December

UK SPACE AGENCY

The Open University

1. Abstract

Expectations of Martian dust devil timings have been based upon the measured diurnal maximum thermal contrast at the planet's surface and observations of terrestrial dust devils, which peak in number in the afternoon[1, 2, 3].

In this work we show that the form of dust devil parameterisation in use within most Mars Global Circulation Models produces an unanticipated level of dust devil activity during morning hours, with many locations experiencing a peak in dust devil activity before mid-sol.

We propose the generally accepted understanding of dust devil behaviour on Mars is incomplete, and that theories of dust devil formation may need to be modified specifically for the Martian environment.

2. Martian Dust Devils

Dust devils are near-surface atmospheric vortices made visible by the particles they lift from the ground and entrain in a vertical, upwardly-spiraling column of air.

Dust devils have been identified in many orbital images of Mars[4, 5] (**Fig. 1**) as well as in images returned from rovers on the surface[6] (**Fig. 2**).

Dust within the Martian atmosphere absorbs incident radiation and re-radiates at infrared wavelengths, heating the immediate surroundings[7]; this heating influences local winds, affecting the transport of dust throughout the atmosphere.

Changes in wind patterns and dust distribution affect surface geological processes as well as modifying the planet's climate. Understanding how dust is injected into the atmosphere is **key to understanding the Martian climate**.

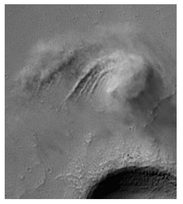


Figure 1. MGS MOC image capturing a large Martian dust devil (400m across) in the Syria/Claritas region. *Image credit NASA/ JPL/Malin Space Science Systems.*

Figure 2. Dust devil imaged from the Martian surface by NASA Mars Exploration Rover Opportunity. *Image credit NASA/ JPL-Caltech.*

3. Modelling the Martian Atmosphere

The Mars Global Circulation Model (MGCM)[8] is a global, three-dimensional model of the Martian atmosphere. Large-scale dynamic circulations and physical processes are modelled explicitly, while smaller scale processes are simulated through parameterisation.

The MGCM dust devil parameterisation[9] models dust devils as convective "heat engines"[10]. The flux of surface dust lifted by dust devils is calculated using the **sensible heat flux** at the planet's surface and the dust devil **thermodynamic efficiency**. The **sensible heat flux** represents the energy available to drive the dust devil. It is found from the surface-to-atmosphere temperature difference, the near-surface atmospheric density and the local horizontal wind speed. The dust devil **thermodynamic efficiency** depends primarily on the depth of the planetary convective boundary layer.

Similar dust devil parameterisations are currently implemented within most other Mars GCMs[11, 12].

4. Results

A. Global Diurnal Dust Devil Activity

We plotted the time-of-sol at which dust devil activity peaked across the Martian surface (**Fig. 3**, **Fig. 4**). Many regions show a range in the timing of dust devil activity, including unanticipated early peaks in activity (**Fig. 5**).

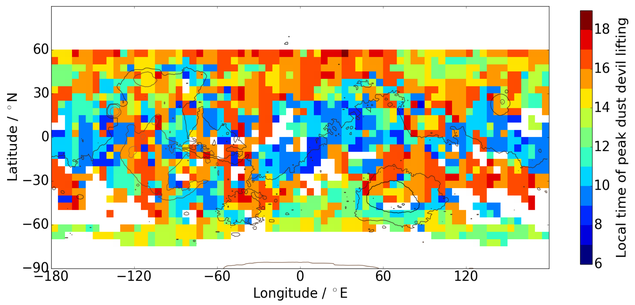


Figure 3. Surface plot, colour scale denotes diurnal timing of peak dust devil lifting. Gridboxes in yellow, orange or red identify afternoon peaks in dust devil lifting; blue gridboxes identify morning peaks. (Displayed data averaged across L_S = 0-30°. White gridboxes indicate zero or near-zero lifting.)

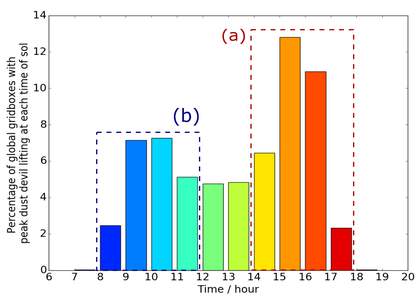


Figure 4. Histogram of the data displayed in Fig. Z, showing (a) the anticipated curve in gridboxes exhibiting peak dust devil lifting during the afternoon and (b) the unanticipated, smaller curve in gridboxes exhibiting peak dust devil lifting during the morning.

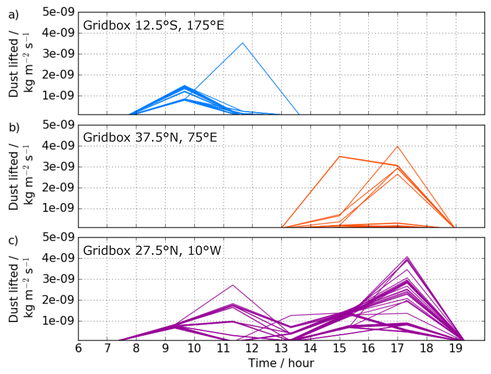


Figure 5. Dust devil lifting within example individual gridboxes through L_S = 120-150°. Each line corresponds to data from one sol (60 sols total). The plots show varying diurnal timings of dust devil lifting: a) morning-only lifting, b) afternoon-only lifting, c) through-sol lifting.

B. Comparison with Surface Observations

Observations made by Mars landers identify more dust devil activity during morning hours than would be expected based solely on insolation-driven near-surface thermal contrast. Our results display a good match with a number of sites; the Pathfinder site is shown in **Fig. 6**. In our results, local sites exhibit a variation in the timing of dust devil lifting between sols.

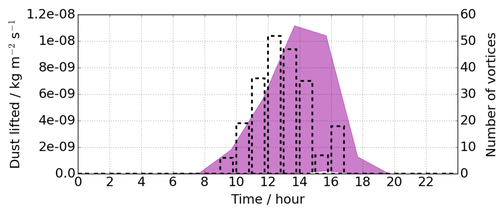
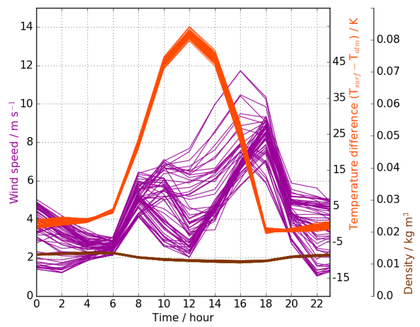


Figure 6. Dust devil activity in the vicinity of the NASA Mars Pathfinder site. The modelled mass of surface dust lifted in each hour (left axis) is marked by purple shading encompassing the range of results obtained through L_S = 140-190°. Dashed bars identify the number of atmospheric vortices (right axis) recorded by the lander[13].

C. Wind Speeds Govern Dust Devil Diurnal Variation

In the 'heat engine' model, the energy that drives dust devil formation is provided by the sensible heat flux at the planet's surface: $F_s = \rho\, c_p\, C_D\, U\, (T_{surf} - T_{atm})$



ρ	near-surface atmospheric density	
T_{surf}	surface temperature	
T_{atm}	near-surface atmospheric temperature	
c_p	specific heat capacity	*constant through our simulations*
C_D	surface drag coefficient	
U	horizontal wind speed	

Figure 7. Diurnal change in variables within an example gridbox (27.5°N, 60°E). Predictable, smoothly varying quantities are plotted against the right axes; the changeable, more rapidly varying wind speed is plotted against the left axis. Each plotted line corresponds to data from one sol (L_S = 120-150°, 60 sols total).

Within the MGCM parameterisation, the timing of the diurnal peak of dust devil lifting is not determined solely by heating due to insolation (**Fig. 7**). While the predictable diurnal variation of atmospheric density and surface-to-atmosphere temperature difference provides the environment within which dust devils **can** form, precisely **when** they form is governed by local wind speeds, which vary strongly and less predictably. Higher wind speeds result in higher levels of dust devil lifting.

5. Conclusions

- Modelled dust devil activity displays a wider diurnal range than was expected from insolation-driven thermal contrast.
- In the MGCM, diurnal **variability** of dust devil activity is governed by local wind speeds. Higher wind speeds generate higher levels of dust devil activity.
- Our results show a good match with a number of surface observations of Martian dust devils, in which landers have observed a range of dust lifting diurnal distributions.
- Theories of terrestrial dust devil formation may need to be further developed, or tailored specifically, to better fit the Martian environment.
- This work should be published in *Icarus* in 2017: Diurnal Variation in Martian Dust Devil Activity (Chapman *et al.*).

References

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Acknowledgements: UK Space Agency funding under grant ST/M00306X/1, UK Science and Technology Facilities Council funding under grant ST/L000776/1.

rhian.chapman@open.ac.uk @RhianInSPACE
open.ac.uk/people/rmc429 @PlanetEnviroOU